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CITATION:

Bhanuchandra, M ...[et al]. Transition-Metal-Free Synthesis of Carbazoles and Indoles by an SN Ar-Based "Aromatic Metamorphosis" of Thiaarenes.. Angewandte Chemie - International Edition 2015, 54(35): 10234-10238

ISSUE DATE:

2015-07-15

URL:

http://hdl.handle.net/2433/201996

Transition-Metal-Free Synthesis of Carbazoles and Indoles via S_NAr-based "Aromatic Metamorphosis" of Thiaarenes

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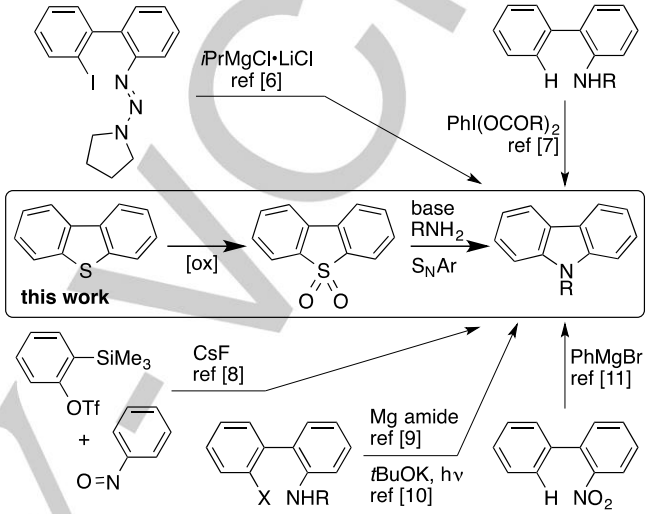
Dibenzothiophene dioxides, readily prepared through oxidation of the parent dibenzothiophenes, undergo nucleophilic aromatic substitution with anilines intermolecularly and then intramolecularly to yield the corresponding carbazoles in a single operation. The "aromatic metamorphosis" of dibenzothiophenes to carbazoles does not require any heavy metals, thus being useful for organic electronics as well as pharmaceutical industry. This strategy is also applicable to the synthesis of indoles. Since electron-deficient thiaarene dioxides exhibit interesting reactivity that the corresponding electron-rich azaarenes do not, a combination of a thiaarene-dioxide-specific reaction with the S_NAr-based aromatic metamorphosis allows for transition-metal-free construction of difficult-to-prepare carbazoles.

Carbazoles represent an important class of heteroaromatic compounds, many of which find a wide range of application as biologically active agents in medicinal chemistry[1] and as hole-transport and light-emitting materials in organic electronics.[2] For the last two decades, transition metal catalysis has attracted attention for constructing a carbazole skeleton via catalytic C-N bond formation, which includes Buchwald-Hartwig or Ullmann-type amination of halobiaryls,[3] oxidative C-H amination of aminobiaryls,[4] or nitrene insertion from azidobiphenyls.[5] Despite the high efficiency and reasonably wide scope, residual transition metal impurities could adversely affect the biological properties or device performances of the final products.

Transition-metal-free synthesis of carbazoles has hence undergone a renaissance for the last few years (Scheme 1). Knochel disclosed that halogen-magnesium exchange of 2-iodo-2'-triazenobiaryls resulted in formation of carbazoles.[6] Chang and Antonchick reported intramolecular oxidative C-H amination of aminobiaryls with hypervalent iodine reagents.[7] Studer invented an interesting approach, i.e., reactions of arynes with nitrosoarenes,[8] although the yields were moderate and the regioselectivity were not well controlled as typically observed in aryne chemistry. Tokuyama developed base-mediated cyclization of 2-amino-2'-bromobiphenyls via arynes.[9] From similar precursors, photoinduced cyclization occurs via a radical process to yield carbazoles.[10] Kürti disclosed facile reductive cyclization of 2-nitrobiaryls by means of PhMgBr.[11] Regardless of these elegant protocols, there still remains ample room to develop novel strategies to prepare carbazoles without recourse to transition metal catalysts.



Scheme 1. Recent strategies for transition-metal-free synthesis of carbazoles

Recently, our group has been interested in developing "aromatic metamorphosis", which represents a transformation of an aromatic system to a different one through partial disassembly of the starting aromatic ring.[12–14] Along this line, here we report transition-metal-free S_NAr-based aromatic metamorphosis of dibenzothiophenes to carbazoles via dibenzothiophene dioxides.

Our strategy begins with smooth oxidation of dibenzothiophenes with aqueous hydrogen peroxide (see Supporting Information (SI)).[15] This conventional process is useful as the first step of the aromatic metamorphosis.

Although aryl sulfones are known to undergo S_NAr reactions, the scope of the substitution is limited.[16–19] Another difficulty should originate from the second intramolecular S_NAr reaction that would involve formal elimination of "K_2SO_2" of high energy.[20] The realization of the second, and the last step, sequential inter/intramolecular nucleophilic aromatic substitution, hence required screening of reaction conditions. We selected the reaction of dibenzo[*b,d*]thiophene 5,5-dioxide (**1a**) with *p*-toluidine (**2a**) as a model reaction for optimization (eq 1). The reaction of **1a** (1.0 equiv) with **2a** (2.0 equiv) by means of lithium hexamethyldisilazide (3.0 equiv) in dioxane at 80 ˚C for 16 h did not produce the desired carbazole **3a**. Interestingly, **3a** was obtained in 50% yield when $NaN(SiMe_3)_2$ was employed. To our delight, $KN(SiMe_3)_2$ (potassium hexamethyldisilazide, KHMDS, 0.5 M toluene solution) gave the best result to isolate **3a** in 94% yield. Other potassium bases such as K_2CO_3, K_3PO_4, KOAc, and KO*t*Bu were totally ineffective. Dioxane has proved to be the best co-solvent with toluene from KHMDS. The reactions in 1,2-dimethoxyethane/toluene and in toluene as a sole solvent delivered **3a** in 91% and 61% yields, respectively. Reducing the amount of **2a** or KHMDS led to lower yields of **3a**.

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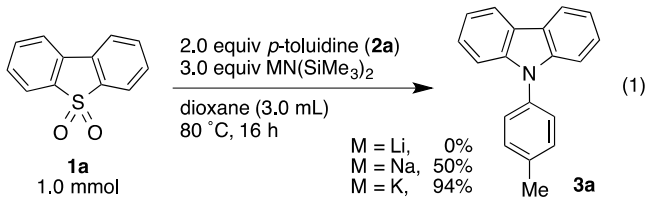
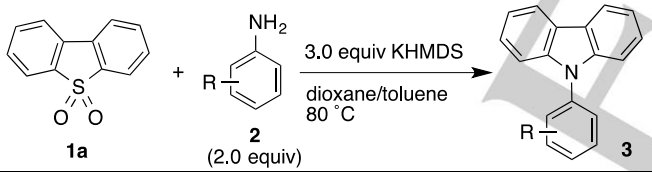


With the optimized conditions in hands, the scope of amines was examined (Table 1). The reactions proceeded efficiently with electron-rich or -neutral anilines to yield **3b–l** in high yields. The vinyl functionality was tolerated under the reaction conditions to afford **3f** in moderate yield. TIPS protection of **2g** partly survived under the reaction conditions to yield a mixture of protected **3g** and unprotected **3h** quantitatively in 1:2.6 ratio. Unfortunately, unprotected *p*-aminophenol (**2h**) reacted sluggishly. Despite its steric hindrance, mesitylamine (**2l**) participated in the reaction to give **3l** in high yield. Moderately electron-withdrawing halo groups retarded the reaction as well as partly underwent dehalogenation. The reaction with 4-chloroaniline (**2m**) yielded a 4:1 mixture of desired **3m** and hydrodechlorinated byproduct **3b** in 64% yield. The fluoro analog **2n** was less reactive to afford **3n** in 30% yield, and the fluoro group was partly substituted with **2n** via an S_NAr reaction to yield *N*-(4-(9-carbazolyl)phenyl)-4-fluoroaniline (**3n'**) as a byproduct. Alkylamines such as *p*-methoxybenzylamine reacted moderately (34% yield with *p*-methoxybenzylamine in 18 h), possibly due to the less acidic NH protons. Attempted phenylation of carbazole with diphenyl sulfone under similar conditions resulted in no conversion probably because of the lower nucleophilicity of potassium carbazolide.

Table 1. Scope of anilines



R	time [h]	3	yield [%]
H	24	**3b**	77
4-MeO	16	**3c**	94
4-*t*Bu	16	**3d**	92
4-Me_2N	17	**3e**	91
4-CH_2=CH	17	**3f**	60
4-TIPSO	17	**3g**	28 (72[a])
4-HO	24	**3h**	26[b]
3-MeO	16	**3i**	70
3,5-tBu_2	17	**3j**	98
3,4-OCH_2O	17	**3k**	65
2,4,6-Me_3	16	**3l**	67
4-Cl	18	**3m**	51 (13[c])
4-F	13	**3n**	30[d] (9[e])

[a] The yield of **3h** as a byproduct. [b] Dioxane (6.0 mL), 100 ˚C. [c] The yield of **3b** as a byproduct. [d] 2.0 equiv of KHMDS. [e] The yield of **3n'** as a byproduct.

The scope of dibenzothiophene dioxide derivatives is wide (Chart 1). Substituted or π-extended carbazoles were obtained efficiently. Gratifyingly, sterically demanding **4g**[21] was obtained in high yield. The reactions of substrates bearing bromo or methoxy groups gave slightly complex mixtures to isolate **4h** or **4i** in moderate yield. Notably, we could synthesize 2,7-diphenyl-9-*p*-tolylcarbazoles (**4c**) in a controlled manner. While electron-rich dibenzothiophene as well as carbazole undergoes electrophilic bromination at the 3,6-positions with exclusive regioselectivity, dibenzothiophene dioxide is electron-deficient to deliver the 2,7-dibromo product (Scheme 2).[15a,22] By changing the oxidation state of sulfur, we could hence alter the positions of substituents in the final carbazoles **4c** and **4d**.[21]

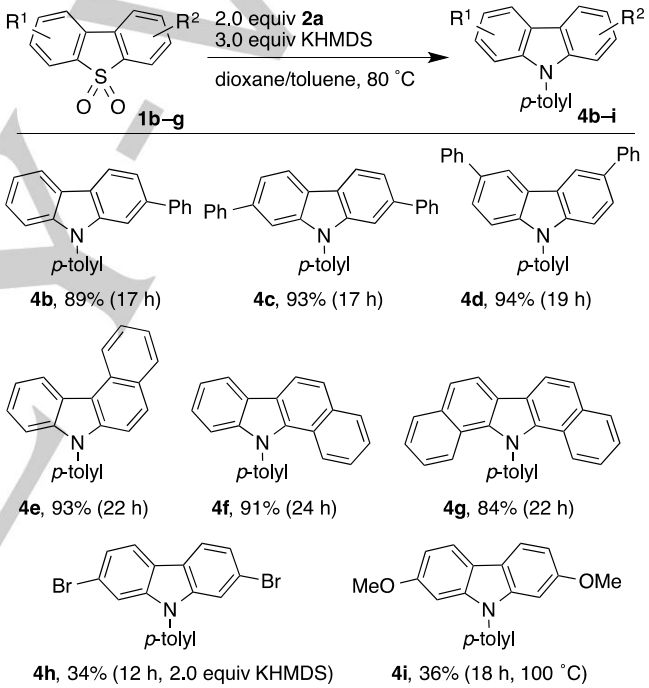
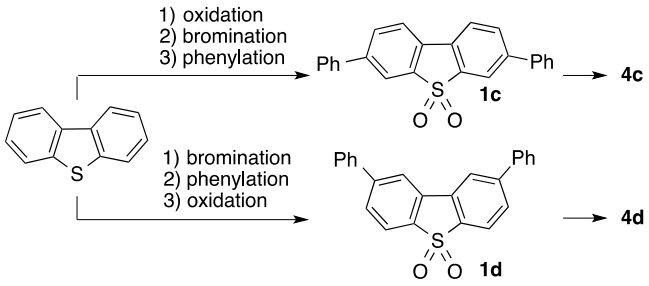


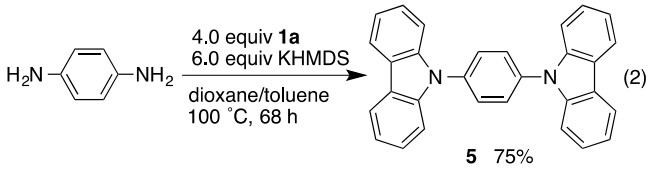
Chart 1. Scope of dibenzothiophene dioxides



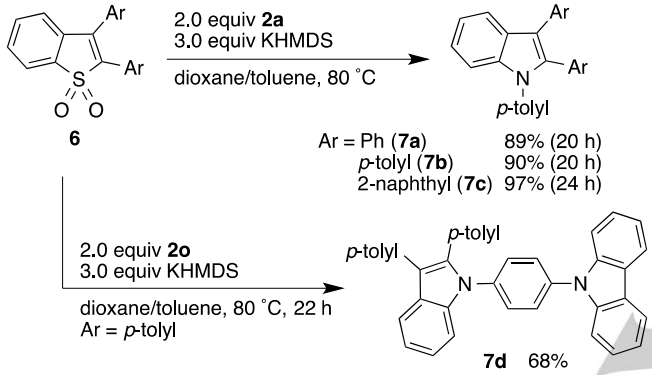
Scheme 2. Selective synthesis of two diphenyl isomers[15a,22b]

Benzene-1,4-diamine reacted with **1a** smoothly to afford bis(carbazolyl)benzene (**5**), an important structural unit that has found diverse applications in electronic devices[23] (eq 2). Usually, bis(carbazolyl)benzenes were obtained in moderate

yields through palladium-catalyzed or copper-mediated reactions of 1,4-dihalobenzene with carbazole at 170–200 ˚C.

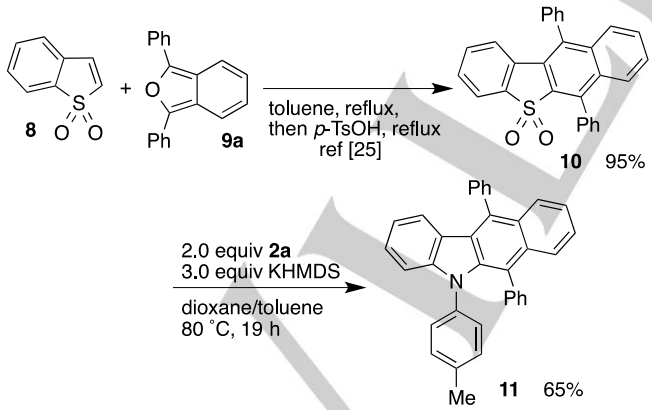


Our S_NAr-based amination was applicable to the synthesis of indoles (Scheme 3). Although 2,3-diaryl groups are necessary to avoid undesired conjugate addition onto the vinyl sulfoxide unit, densely arylated indoles **7a**–**c**[21] were formed in excellent yields. The reaction of **6** with 4-(9-carbazolyl)aniline (**2o**) yielded an unsymmetric indole-carbazole hybrid **7d**, which will find applications in organic EL.[24]



Scheme 3. S_NAr-based synthesis of indoles

Electron-deficient benzothiophene dioxide **8** showed uniquely high reactivity as a dienophile in the Diels-Alder reaction with isobenzofuran **9a**[25] whereas indoles do not react with **9a**. Taking advantage of the Diels-Alder reaction, we could extend π-conjugation to form benzonaphthothiophene dioxide **10** (Scheme 4). Eventually, π-extended benzocarbazole **11** was obtained in good overall yield from commercially available **8**.

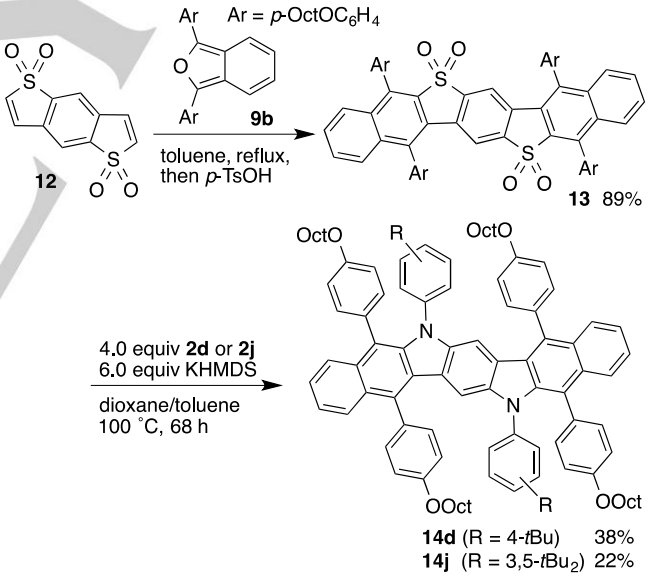


Scheme 4. Sequential Diels-Alder reaction/carbazole formation

We applied this Diels-Alder-based approach to achieve significantly π-extended dibenzoindolo[3,2-*b*]carbazoles **14** (Scheme 5). The precursor bissulfone **13** was obtained from rather small aromatic compound **12** in 89% yield. Subsequently, expected quadruple C–N bond formations occurred to give **14d** and **14j** in 38% and 22% yields, respectively. In comparison with elegant yet burdensome construction of similar dibenzoindolo[3,2-*b*]carbazoles for OFET devices,[26,27] this overall transformation highlights the synthetic potential of our carbazole synthesis.

Figure 1 shows the UV/visible and fluorescence spectra of **14j** in dichloromethane.[28] The lowest energy absorption maximum was observed at 496 nm, which is significantly red shifted compared to typical absorption of indolo[3,2-*b*]carbazoles (420–440 nm).[29] Compound **14j** showed bright green fluorescence that has its intensity maximum at 511 nm with a fluorescence quantum yield of 34%. Our S_NAr-based approach is thus useful to explore π-extended carbazoles that show interesting functions.

The most likely mechanism would be the sequential inter/intramolecular S_NAr reactions with highly nucleophilic potassium amides (Scheme 6). The first intermolecular S_NAr reaction would be faster than the second intramolecular reaction of **15**,[30] and the carbazole formation necessitates a high temperature. The following experiments strongly support the mechanism (Scheme 7): **1a** reacted with **2a** with the aid of KHMDS at room temperature to isolate zwitterionic **16**.[21] Subsequent exposure of **16** to KHMDS at 80 ˚C afforded **3a** quantitatively. Although there are several debatable reaction pathways for aromatic substitution of aryl sulfones,[18] the isolation of **16** strongly indicates the intermediacy of **15** and hence the S_NAr pathway in our case.



Scheme 5. Concise synthesis of π-extended dibenzoindolo[3,2-*b*]carbazoles

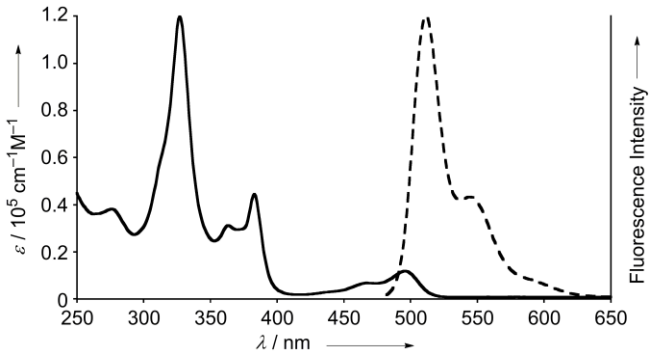
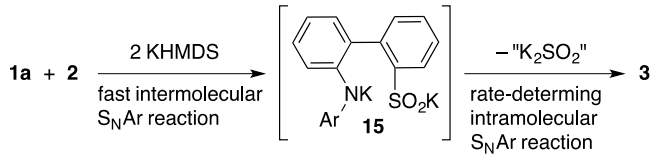
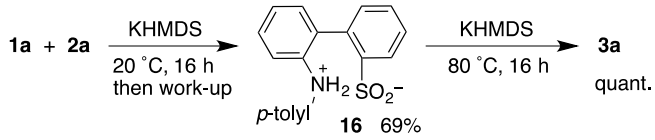


Figure 1. UV/visible (solid line) and fluorescence (dotted line) spectra of **14j** in CH_2Cl_2



Scheme 6. Plausible mechanism



Scheme 7. Elucidation of mechanism

In conclusion, we have reported a new powerful and practical strategy to prepare carbazoles without recourse to transition metal catalysts. Dibenzothiophene dioxide derivatives undergo sequential inter/intramolecular nucleophilic aromatic substitution with anilines with the aid of KHMDS to afford a wide range of carbazoles in one shot. Considering that dibenzothiophene dioxides are readily available by oxidation of the parent dibenzothiophenes, one can concisely achieve aromatic metamorphosis of dibenzothiophenes to carbazoles. Since electron-deficient thiophene dioxides exhibit reactivity different from that of the corresponding electron-rich azaarenes, coupling a thiaarene-dioxide-specific reaction with the S_NAr carbazole synthesis opens up a new route to uneasy-to-access carbazoles. Current efforts are directed toward exploring new aromatic metamorphosis in our laboratory.

Acknowledgements

This work was supported by Grants-in-Aid from MEXT (Nos.: 25107002 “Science of Atomic Layers”) and from JSPS (Nos.: 24685007 (Young Scientists (A)), 26620081 (Exploratory Research)). D.V. and K.M. thank JSPS for financial support. H.Y. acknowledges Japan Association for Chemical Innovation for financial support.

Keywords: Nucleophilic aromatic substitution • Amination • Nitrogen heterocycles • Sulfur heterocycles • Aromatic metamorphosis

[1] a) H.-J. Knölker, K. R. Reddy, *Chem. Rev.* **2002**, *102*, 4303; b) H.-J. Knölker, *Chem. Lett.* **2009**, *38*, 8; c) I. Bauer, H.-J. Knölker, *Top. Curr. Chem.* **2012**, *309*, 203; d) A. W. Schmidt, K. R. Reddy, H.-J. Knölker, *Chem. Rev.* **2012**, *112*, 3193.

[2] a) P. Strohriegl, J. V. Grazulevicius, *Adv. Mater.* **2002**, *14*, 1439; b) J. V. Grazulevicius, P. Strohriegl, J. Pielichowski, K. Pielichowski, *Prog. Polym. Sci.* **2003**, *28*, 1297; c) N. Blouin, M. Leclerc, *Acc. Chem. Res.* **2008**, *41*, 1110.

[3] Double arylation of primary amines with 2,2'-dihalobiaryls: a) K. Nozaki, K. Takahashi, K. Nakano, T. Hiyama, H.-Z. Tang, M. Fujiki, S. Yamaguchi, K. Tamao, *Angew. Chem.* **2003**, *115*, 2097; *Angew. Chem. Int. Ed.* **2003**, *42*, 2051; b) T. Kitawaki, Y. Hayashi, N. Chida, *Heterocycles* **2005**, *65*, 1561; c) A. Kuwahara, K. Nakano, K. Nozaki, *J. Org. Chem.* **2005**, *70*, 413; d) T. Kitawaki, Y. Hayashi, A. Ueno, N. Chida, *Tetrahedron* **2006**, *62*, 6792; e) T. Q. Hung, N. N. Thang, D. H. Hoang, T. T. Dang, A. Villinger, P. Langer, *Org. Biomol. Chem.* **2014**, *12*, 2596. With cyclic diaryliodonium salts: f) D. Zhu, Q. Liu, B. Luo, M. Chen, R. Pi, P. Huang, S. Wen, *Adv. Synth. Catal.* **2013**, *355*, 2172; g) S. Riedmuller, B. J. Nachtsheim, *Beilstein J. Org. Chem.* **2013**, *9*, 1202.

[4] a) J. A. Jordan-Hore, C. C. C. Johansson, M. Gulias, E. M. Beck, M. J. Gaunt, *J. Am. Chem. Soc.* **2008**, *130*, 16184; b) S. H. Cho, J. Yoon, S. Chang, *J. Am. Chem. Soc.* **2011**, *133*, 5996; c) S. W. Youn, J. H. Bihn, B. S. Kim, *Org. Lett.* **2011**, *13*, 3738; d) Q. Jiang, D. Duan-Mu, W. Zhong, H. Chen, H. Yan, *Chem. Eur. J.* **2013**, *19*, 1903; e) M. Yamamoto, S. Matsubara, *Chem. Lett.* **2007**, *36*, 172.

[5] a) B. J. Stokes, B. Jovanovic, H. Dong, K. J. Richert, R. D. Riell, T. G. Driver, *J. Org. Chem.* **2009**, *74*, 3225; b) B. J. Stokes, K. J. Richert, T. G. Driver, *J. Org. Chem.* **2009**, *74*, 6442.

[6] C.-Y. Liu, P. Knochel, *Org. Lett.* **2005**, *7*, 2543.

[7] a) Reference 4b; b) A. P. Antonchick, R. Samanta, K. Kulikov, J. Lategahn, *Angew. Chem.* **2011**, *123*, 8764; *Angew. Chem. Int. Ed.* **2011**, *50*, 8605.

[8] S. Chakrabarty, I. Chatterjee, L. Tebben, A. Studer, *Angew. Chem.* **2013**, *125*, 3041; *Angew. Chem. Int. Ed.* **2013**, *52*, 2968.

[9] T. Noji, H. Fujiwara, K. Okano, H. Tokuyama, *Org. Lett.* **2013**, *15*, 1946.

[10] W. D. Guerra, R. A. Rossi, A. B. Pierini, S. M. Barolo, *J. Org. Chem.* **2015**, *80*, 928.

[11] H. Gao, Q.-L. Xu, M. Yousufuddin, D. H. Ess, L. Kürti, *Angew. Chem.* **2014**, *126*, 2739; *Angew. Chem. Int. Ed.* **2014**, *53*, 2701.

[12] D. Vasu, H. Yorimitsu, A. Osuka, *Angew. Chem. Int. Ed.* **2015**, *54*, 7162.

[13] Diels-Alder reactions of five-membered heteroaromatics and azines with alkenes or alkynes result in aromatic metamorphosis to the corresponding aromatic rings with extrusion of their heteroatomic units. Very recent examples: a) A. Criado, M. Vilas-Varela, A. Cobas, D. Pérez, D. Peña, E. Guitián, *J. Org. Chem.* **2013**, *78*, 12637; b) X. Ding, S. T. Nguyen, J. D. Williams, N. P. Peet, *Tetrahedron Lett.* **2014**, *55*, 7002; c) S. P. J. T. Bachollet, J. F. Vivat, D. C. Cocker, H. Adams, J. P. A. Harrity, *Chem. Eur. J.* **2014**, *20*, 12889; d) S. Suzuki, Y. Segawa, K. Itami, J. Yamaguchi, *Nature Chem.* **2015**, *7*, 227.

[14] Reviews on catalytic denitrogenative transannulation of triazoles: a) B. Chattopadhyay, V. Gevorgyan, *Angew. Chem.* **2012**, *124*, 886; *Angew. Chem. Int. Ed.* **2012**, *51*, 862; b) P. Anbarasan, D. Yadagiri, S. Rajasekar, *Synthesis* **2014**, *46*, 3004.

[15] a) Z. Duan, X. Huang, S. Fujii, H. Kataura, Y. Nishioka, *Chem. Lett.* **2012**, *41*, 363; b) S. F. Nelsen, Y. Luo, M. N. Weaver, J. V. Lockard, J. I. Zink, *J. Org. Chem.* **2006**, *71*, 4286; c) G. Barbarella, L. Favaretto, A. Zanelli, G. Gigli, M. Mazzeo, M. Anni, A. Bongini, *Adv. Funct. Mater.* **2005**, *15*, 664.

[16] Intramolecular Smiles rearrangement is a well-known transformation that includes an S_NAr reaction of aryl sulfones: W. E. Truce, E. M. Kreider, W. W. Brand, *Org. React.* **1970**, *18*, 99.

[17] Some aryl sulfones undergo S_NAr substitution with amines under highly basic conditions. For instance, see: a) W. Bradley, *J. Chem. Soc.* **1938**, 458; b) G. Köbrich, *Chem. Ber.* **1959**, *92*, 2981.

[18] Diphenyl sulfone reacted with fused potassium hydroxide to afford phenol: a) S. Oae, N. Furukawa, *Bull. Chem. Soc. Jpn.* **1966**, *39*, 2260. Dibenzothiophene dioxides reacted with potassium alkoxide or hydroxide at ca. 160 °C to yield the simply ring-opening product via one S_NAr process: b) T. G. Squires, C. G. Venier, B. A. Hodgson, L. W. Chang, *J. Org. Chem.* **1981**, *46*, 2373; c) T. Aida, T. G. Squires, C. G. Venier, *Tetrahedron Lett.* **1983**, *24*, 3543.

[19] Reactive azaaryl sulfones such as tetrazolyl sulfones are well known to undergo intermolecular S_NAr substitution with a variety of nucleophiles. For instance: a) P. J. Kocienski, A. Bell, P. R. Blakemore, *Synlett* **2000**, 365; b) C. Aissa, *J. Org. Chem.* **2006**, *71*, 360; c) P. Jankowski, K. Plesniak, J. Wicha, *Org. Lett.* **2003**, *5*, 2789.

[20] K_2SO_2 is an elusive species: a) P. J. Bruna, F. Grein, *J. Phys. Chem. A* **2012**, *116*, 10229; b) D. P. Morales, A. S. Taylor, S. C. Framer, *Molecules* **2010**, *15*, 1265.

[21] X-ray crystallographic analysis unambiguously revealed the structure. For details, see SI.

[22] a) L. Zhang, S. Zeng, L. Yin, C. Ji, K. Li, Y. Li, Y. Wang, *New J. Chem.* **2013**, *37*, 632; b) A. Heynderickx, A. Samat, R. Guglielmetti, *Synthesis* **2002**, 213.

[23] a) B. E. Koene, D. E. Loy, M. E. Thompson, *Chem. Mater.* **1998**, *10*, 2235; b) H.-P. Shi, J.-X. Dai, L.-W. Shi, M.-H. Wang, L. Fang, S.-M. Shuang, C. Dong, *Chem. Commun.* **2012**, *48*, 8586; c) Q. Zhang, J. Chen, Y. Cheng, L. Wang, D. Ma, X. Jing, F. Wang, *J. Mater. Chem.* **2004**, *14*, 895.

[24] T. Iwakuma, H. Yamamoto, Y. Hironaka, H. Ikeda, C. Hosokawa, S. Tomita, T. Arakane (Idemitsu Kosan Co., Ltd.), US 8580391 B2, **2013**.

[25] M. Nandakumar, J. Karunakaran, A. K. Mohanakrishnan, *Org. Lett.* **2014**, *16*, 3068.

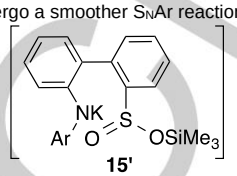
[26] M. T. Levick, I. Grace, S.-Y. Dai, N. Kasch, C. Muryn, C. Lambert, M. L. Turner, D. J. Procter, *Org. Lett.* **2014**, *16*, 2292.

[27] Importance of benzobipyrroles in organic electronics: H. Tsuji, Y. Yokoi, C. Mitsui, L. Ilies, Y. Sato, E. Nakamura, *Chem. Asian J.* **2009**, *4*, 655 and references cited therein.

[28] The photophysical properties of **14d** are very similar to those of **14j**. For details, see SI.

[29] a) J. Simokaitiene, E. Stanislovaityte, J. V. Grazulevicius, V. Jankauskas, R. Gu, W. Dehaen, Y.-C. Hung, C.-P. Hsu, *J. Org. Chem.* **2012**, *77*, 4924; b) K. Kawaguchi, K. Nakano, K. Nozaki, *J. Org. Chem.* **2007**, *72*, 5119.

[30] The elimination of elusive and high-energy K_2SO_2 is unlikely. After many experiments, at this stage we speculate that trimethylsilylation of **15** with $HN(SiMe_3)_2$ generated in situ would take place to afford **15'**, which should undergo a smoother S_NAr reaction.



15'

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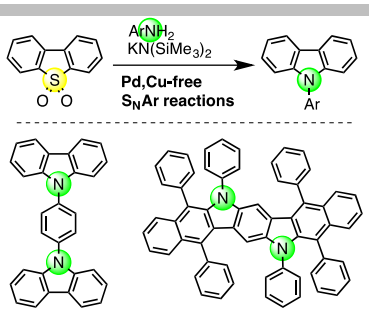
COMMUNICATION

Dibenzothiophene dioxides undergo sequential inter- and intramolecular nucleophilic aromatic substitution with anilines to yield the corresponding carbazoles in a single operation. This approach to carbazole needs no heavy metals, thus being useful for organic electronics as well as pharmaceutical industry. Coupling a thiaarene-dioxide-specific reaction with the S_NAr carbazole synthesis allows for construction of uneasy-to-access carbazoles.



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Transition-Metal-Free Synthesis of Carbazoles and Indoles via S_NAr-based "Aromatic Metamorphosis" of Thiaarenes